Aqueous or Slow-Release? Considerations for Substrate Selection

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Still No Silver Bullet?

- **To date, no single electron donor has been demonstrated to satisfy the requirements for all sites**
- **Luckily, the myriad of available donors can be divided into two broad categories: aqueous and slow-release**
- **The choice of either an aqueous or slow-release electron donor, or a combination of both, should be made based on site-specific remediation goals, hydrogeologic conditions, cost, and land-use issues**

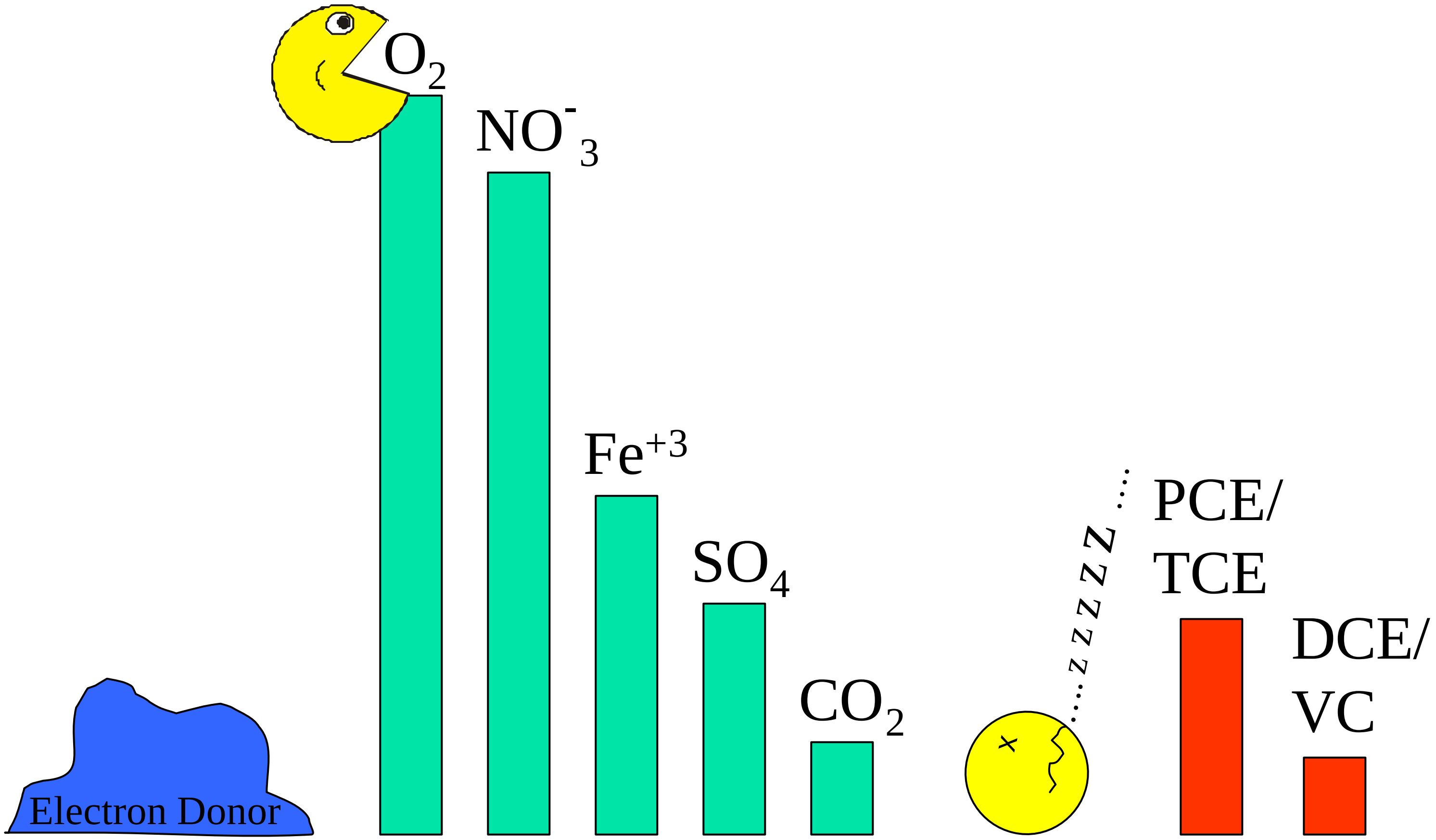
General Selection Factors

- Application Type
  - Inundation vs. Barrier
- Distribution
  - Treatment area size, number and depth of wells required, etc.
- Presence of Residual Source
- Vertical Extent of Contamination
- Buffering Capacity of Aquifer
- Land Use
- "Remoteness" of Site
- Impact on Microbial Community Efficiency
- Trace Contaminants in Donor
- Demonstrated Performance
- Cost

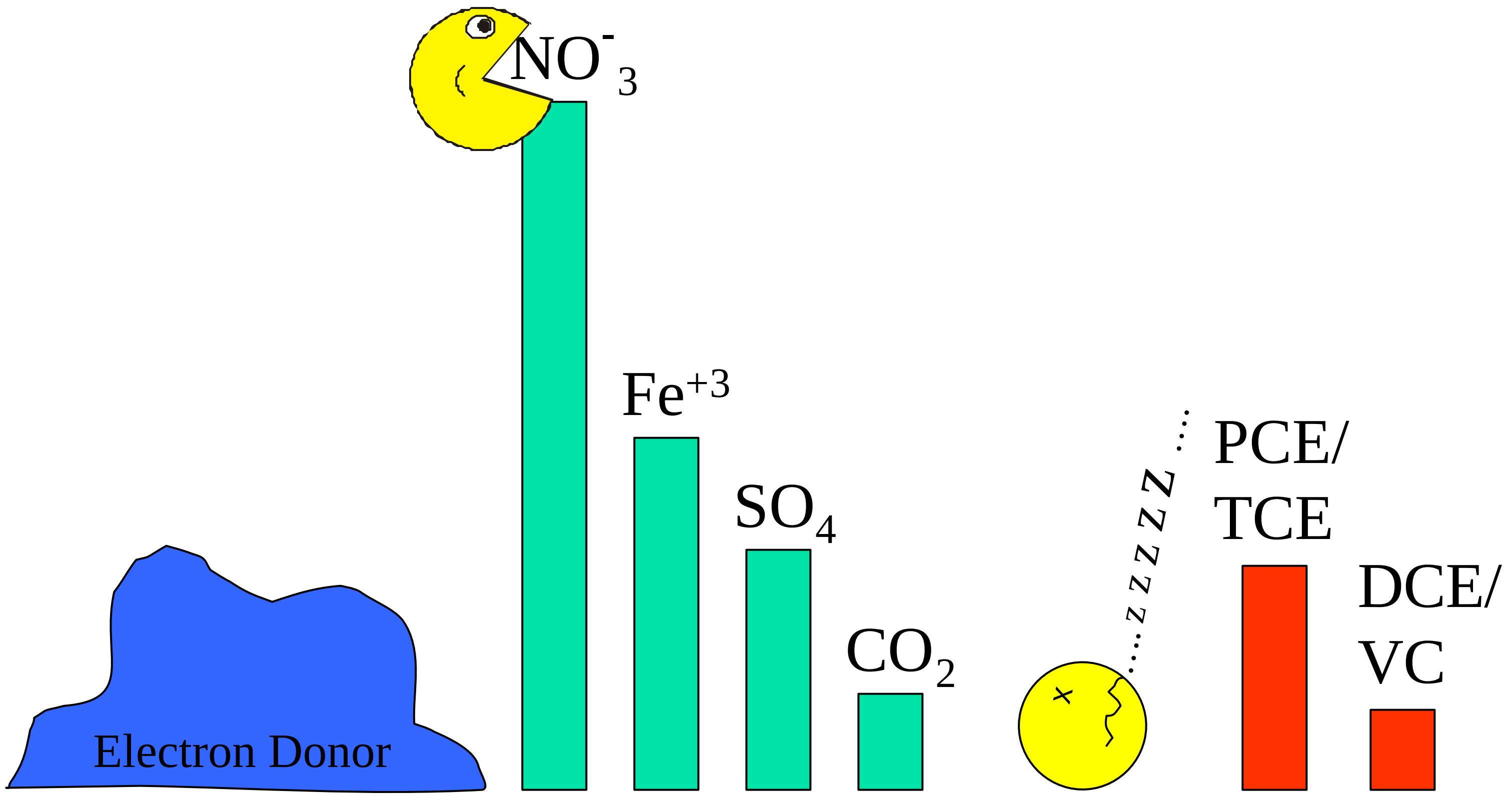
Delivery, Delivery, Delivery

- Distribution of donor is critical: presence of donor → reducing conditions → dechlorination
- Many factors affect the ease of delivery, and with it, the selection of an appropriate electron donor:
  - Volume Requiring Treatment
  - Depth to Water
  - Aquifer Permeability
  - Ambient Aquifer Flow Rates
  - Aquifer Dispersivity
  - Potential for Preferential Flow (Heterogeneity)
  - Viscosity of Donor Solution (including temperature dependence)
  - Solubility of Donor/Transport Characteristics

Electron Donor, Redox Conditions, and Dechlorination



Electron Donor, Redox Conditions, and Dechlorination



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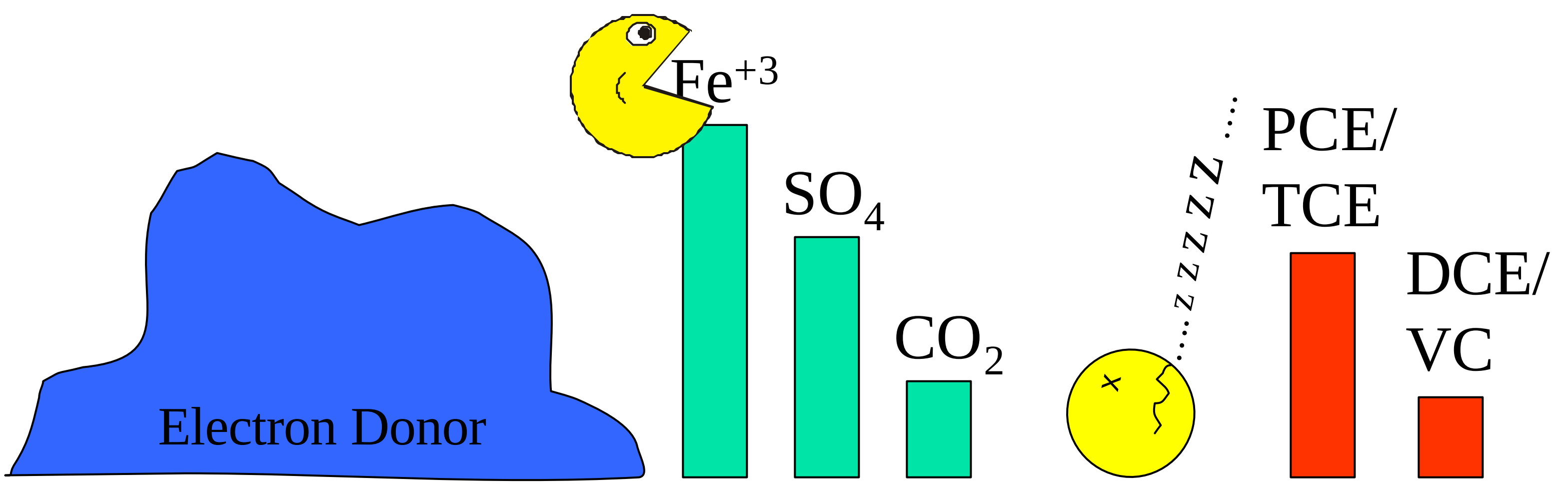

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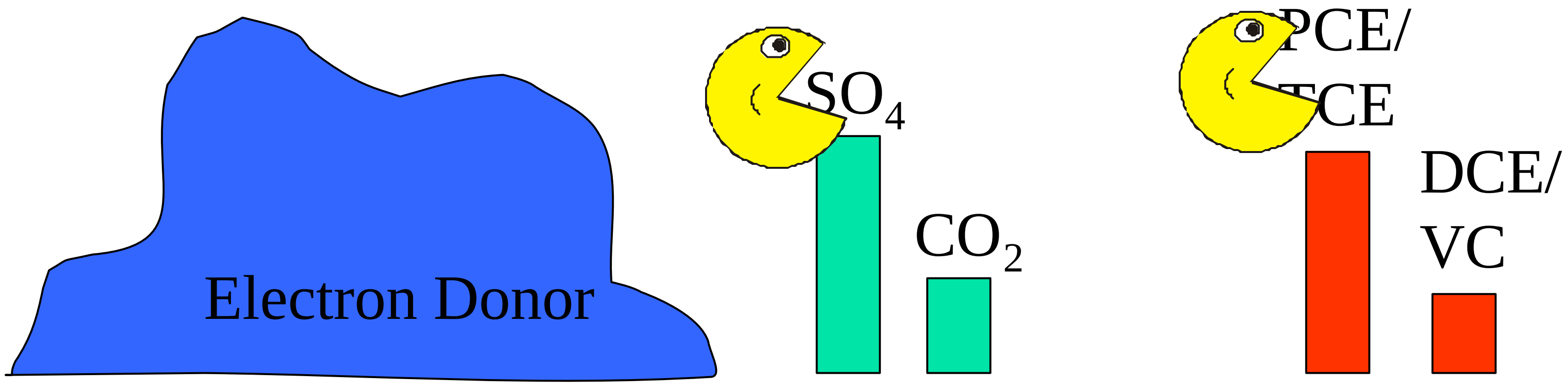
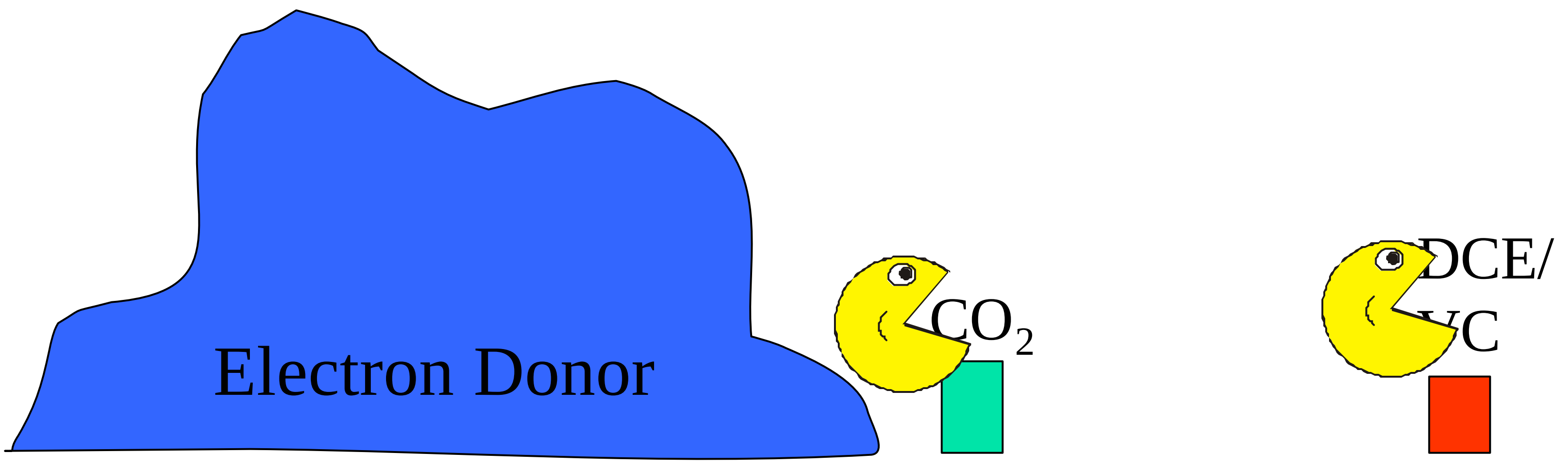


Electron Donor, Redox Conditions, and Dechlorination



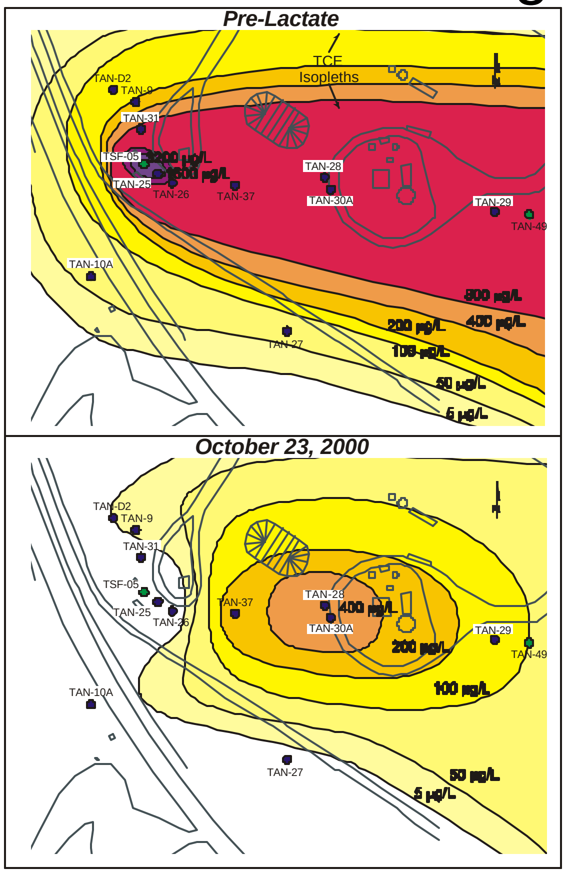
Aqueous Electron Donors

- Lactate (salt or acid)
- Propionate (salt or acid)
- Butyrate (salt or acid)
- Acetate (salt or acid)
- Benzoate (salt or acid)
- Methanol
- Molasses
- Whey
- Alcohols

- General Properties
  - Viscosity: low (similar to water)
  - Density: can be slightly less than water to significantly greater for concentrated salts
  - Solubility: high
  - Enhanced Bioavailability: low to high

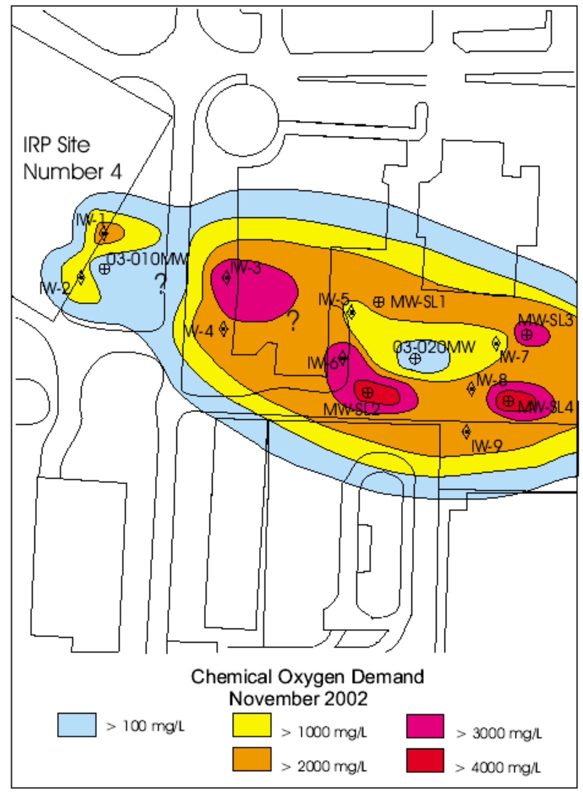
Implications for AqEDs

- Low viscosity and high solubility make distribution in the subsurface very easy, which means fewer injection locations for large areas



Test Area North:

Single injection well provided treatment for an area approximately 200 ft in diameter (TCE contours shown)



Courtesy SAIC

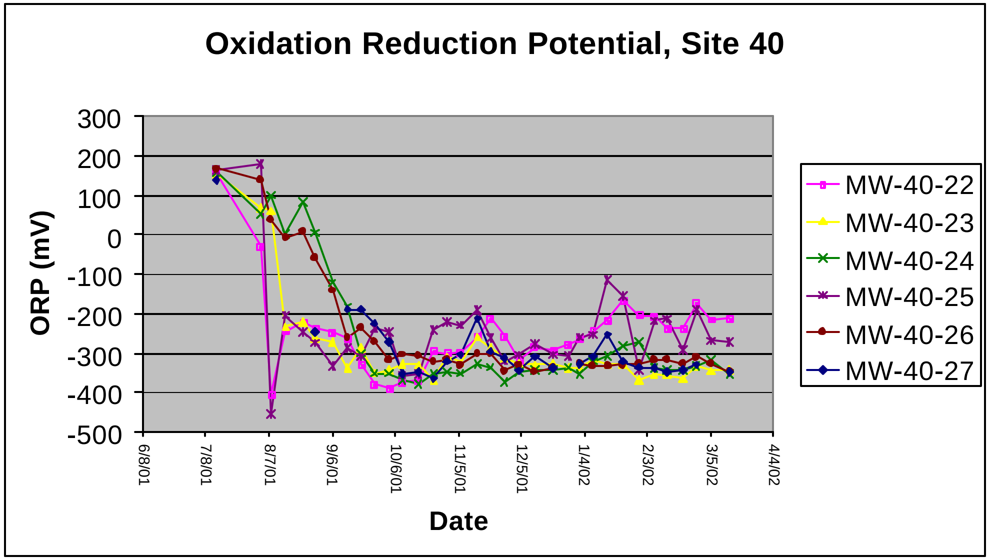
Air National Guard Site:

Nine manifolded injection wells provided treatment for an area approximately 1800 ft long and 900 ft wide (COD concentrations shown are almost 2 months after an injection)

Implications for AqEDs

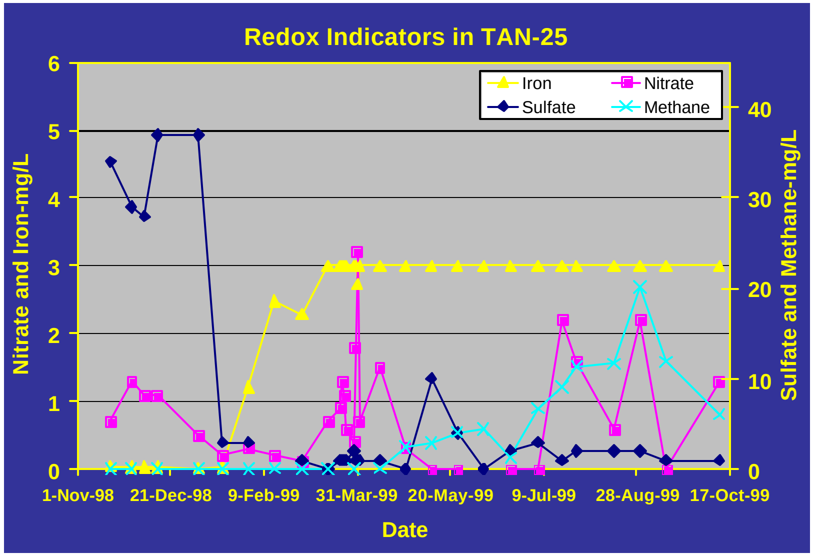
- High solubility and ease of distribution facilitates rapid shift in redox conditions to expedite dechlorination

First 8 Months at Seal Beach



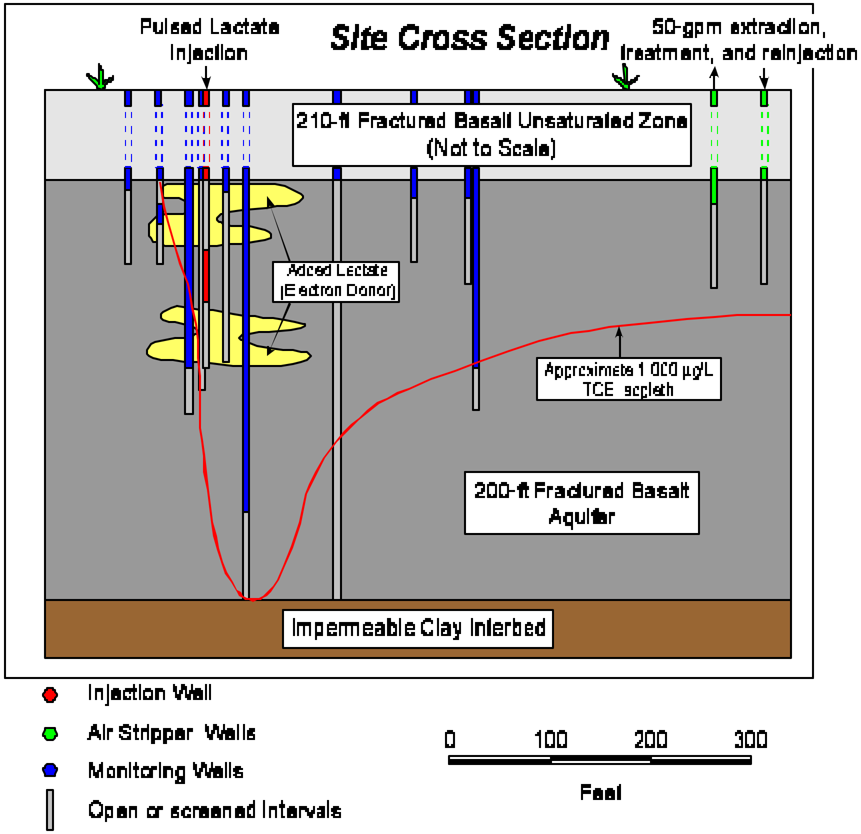
Courtesy Bechtel Environmental, Inc.

First 9 Months at Test Area North



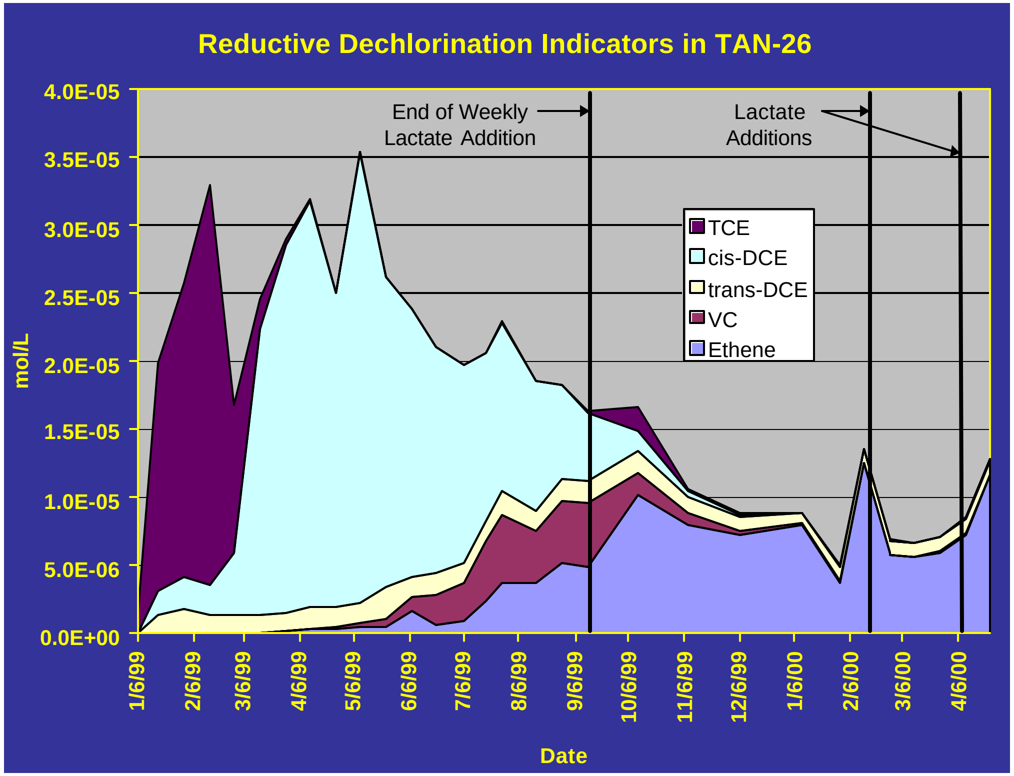
Implications for AqEDs (cont.)

- Density variability along with low viscosity and high solubility allows the option of vertical distribution either through infiltration, or a partially penetrating well



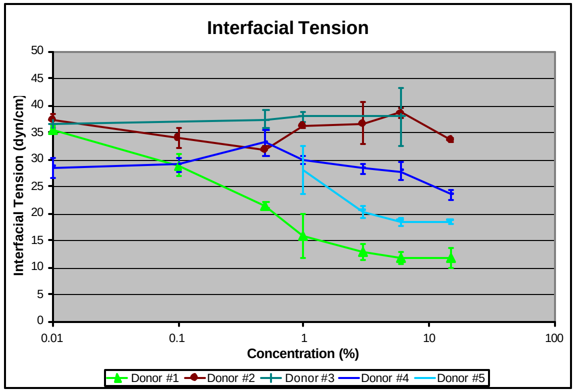
Implications for AqEDs (cont.)

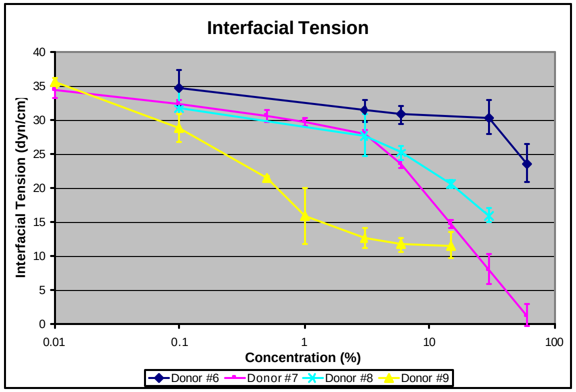
- High solubility generally means a short to medium lifespan in the field (a 6-8 week lactate injection frequency appeared to give the best dechlorination at TAN)



Implications for AqEDs (cont.)

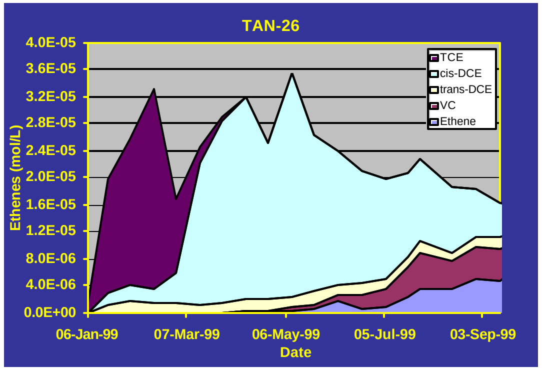
- Bioavailability Enhancement Technology™ (B.E.T.™) can be used to accelerate removal of residual source material, while retaining the benefits of in situ bioremediation



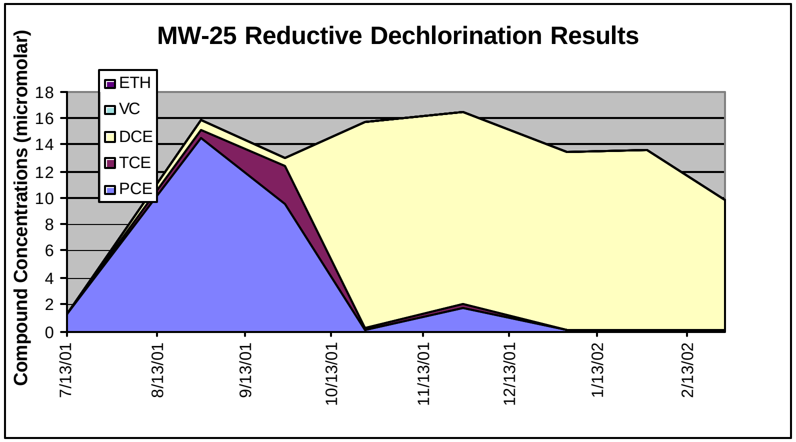


Decreases in IFT caused by some electron donor solutions can increase effective solubility of residual nonaqueous contaminants, thereby enhancing bioavailability and accelerating mass removal

Test Area North



Seal Beach

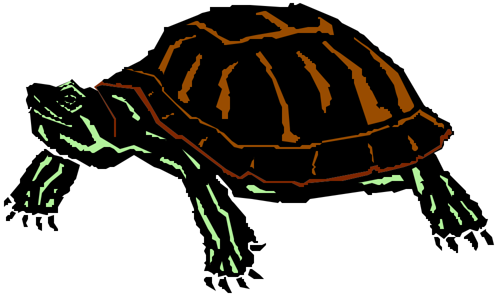


Courtesy Bechtel Environmental, Inc.

Slow-Release Electron Donors

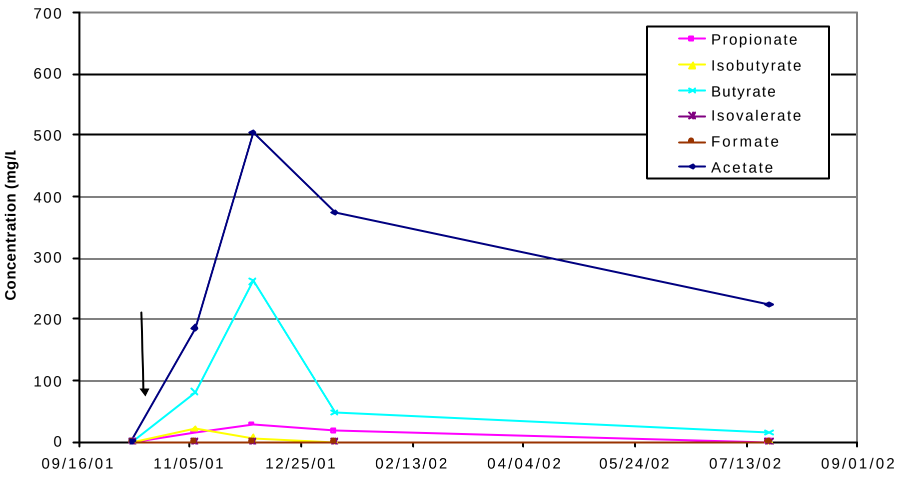
- HRC®
- Vegetable Oil
- Polymeric Organic Materials (chitin, bark mulch)
- LactOil™

- General Properties
  - Viscosity: high to solid
  - Density: can be less than or similar to water for liquids
  - Solubility: low (generally nonaqueous)
  - Enhanced Bioavailability: low (can sequester contaminants) to high (maybe)

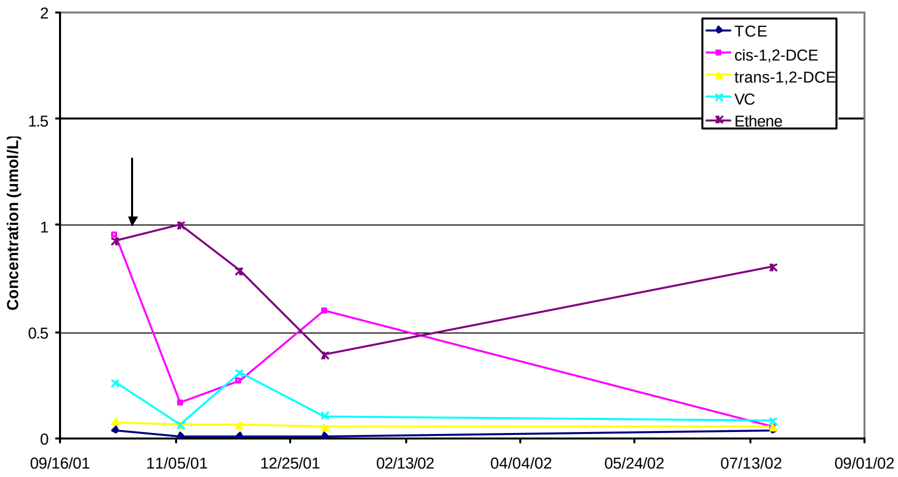


Implications for SREDs

- Low solubility ensures medium to long lifespans for slow-release donors in the subsurface. HRC® may last about 1 year, vegetable oil for several years, and chitin has been shown to facilitate dechlorination for more than 9 months in a low-permeability field application. For variably saturated conditions, solid-phase donors will be especially long-lived.



VFAs



Chloroethenes

Implications for SREDs

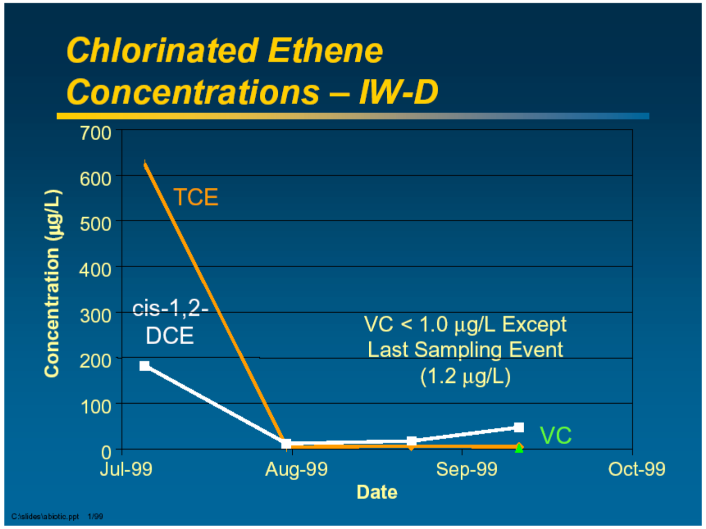
- High viscosity and/or nonaqueous nature of most slow-release electron donors limits the ability to distribute them throughout large volumes
  - Delivery can be achieved through several techniques: a large grid or barrier of closely spaced injection s, trenching, or soil fracturing
  - Except for soil fracturing, these techniques are generally cost-effective only in relatively shallow environments

- This distribution limitation might be overcome through the use of less viscous emulsions of vegetable oil, LactOil™, or similar substrates

Implications for SREDs

- Effects of slow-release electron donors on bioavailability are highly variable.
  - Nonaqueous liquids such as vegetable oil are likely to sequester contaminants due to their affinity for the organic phase
  - Solid donors such as chitin and bark mulch will not impact interfacial tension, but may benefit from accelerated dissolution due to biodegradation in the aqueous phase
  - Donors that combine an immediate decrease in interfacial tension with a longer term nonaqueous phase may increase bioavailability initially, then sequester contaminants

TCE sequestration by VegOil at Hill AFB



Courtesy Parsons Engineering Science

Some Suggested Applications

Aqueous

- Sites where distribution is challenging (e.g., large, deep, or marginal-permeability sites)
- Residual source areas where contaminant mass removal is desired
- Initial applications for establishing reducing conditions quickly

Slow-Release

- Sites where distribution can be facilitated with closely spaced wells, especially via direct-push (emulsified oils or LactOil™ may be more robust)
- Barriers (consider possible decreased conductivity)
- Residual source areas where contaminant sequestration is acceptable
- Variably saturated sites